CHAPTER 5 - ENERGY SUSTAINABILITY

"*Right now more energy passes through the windows of buildings in the U.S. than flows through the Alaska pipeline.*" K. Bidwell and P. A. Quinby (see Internet references for Chapter 1)

5.1 Introduction

This chapter deals with one of the most important problems that the world faces today. Conventional sources of energy are diminishing, and some researchers have already hinted at a time horizon for their depletion. It certainly means that the oil and carbon reserves that remain for future generations will not suffice for their needs. It is possible that those people might find better uses for these energy sources as raw materials — rather than contaminating the atmosphere by burning them, as humankind now does.
The technology already exists — and, naturally, it can be improved — for the sustainable use of **non-conventional energy or renewable energy sources (RES),** with the aim of slowing down our extraction and consumption rate of fossil fuels, while at the same time doing a favour to the planet's battered environment.

Consequently, this chapter briefly analyses the different possibilities humankind has at the present for developing and utilizing these non-conventional sources. Naturally, these descriptions can only glimpse at each alternative, since it is not the purpose of this book to analyse each one at depth. The aim is simply to make the reader aware of the different options, their main characteristics, and some actual applications or cases. Examples of operating stations are provided to show that these schemes are not only possible, but are really in operation and already contributing to decreasing the amounts of fossil fuels now employed.

Of paramount importance is the cost per kWh. In general, the cost per kWh of non-conventional alternatives has been declining because of the use of new materials, higher efficiencies and increasing demand. However, with the possible exception of wind energy, the cost per kWh generated for non-conventional alternatives still remains higher than electricity generated by conventional sources; this is one of the reasons why progress has not been faster. In other words, the utilization of these promising techniques is greatly affected by the influence of economics. Besides, consider that conventional

utility plants have a price per kWh that relates to the size of the undertaking that is large plants — as is usually the case — offer the benefits of **economies of scale** (see Glossary).

However, to directly compare costs between these two different modes of generation is incorrect, being much like the proverbial comparison between apples and oranges. A proper comparative assessment of conventional and non-conventional energy sources requires calculating the production costs as well as the 'hidden' costs that is the **environmental and social costs** associated with the extraction of resources, their processing, and their further utilization in a power plant. Thus, for to calculate the real cost per kWh from a coal-fired power plant requires also taking into account:

- The Life Cycle Assessment (see Appendix, section A.5) of coal extraction, transportation and utilization. That is, how much energy — which translates mainly into CO_2 contamination — is spent to mine coal, and how much is used to transport it to where it is consumed?
- The cost of the pollution produced by smokestacks from power plants, measured in CO_2 and other sulphurous gases, which leads to global warming and acid rain.
- The amount of residues from smoke filters that will be dumped into the soil, and the cost to clean it up.
- The number of people affected by pulmonary diseases due to smokestack gases. If in any doubt about this effect, we need only consider the problems generated in Krakow and Katowice, in Poland, due to the coal exploitation and industrial utilization in that area;
- The energy and pollution caused by making boilers, turbines, condensers, electrical equipment, etc., should also be considered.

Similar things apply to oil-fired power generation plants.

- What about nuclear plants? After decades of operation, it is said that society gets good value for its money and this with 'clean' energy production. Consider that it is deemed clean only because no noticeable radiation emanates from the plants or smokestacks, but it is important to also bear in mind that nobody has yet figured out what to do with nuclear wastes, which for centuries may contaminate soil and water.

Finally, if someone discovers a process to treat radioactive waste or to render it harmless, or if a place is found where it can be safely buried, how much will that cost? Even in such a case, this generation is merely ‘passing the buck’ for coming generations to get rid of radioactive wastes that we produce. It appears that this generation is extending its footprint (section 1.6) not only in space but also in time, to the future.

When we calculate all of these costs, what is the actual price per kWh produced by coal, oil or nuclear plants, as compared to by RES? Obviously, to undertake an evaluation requires performing the same analysis for non-conventional sources, since they also generate pollution, thus increasing the cost per kWh generated. What might these costs be?

- For wind energy (section 5.3.1) it is again necessary to apply the Life Cycle Assessment to learn the amount of pollution caused by extracting the raw materials used for the construction of blades and gear boxes for wind turbines, as well as for the cement or steel towers supporting them.

- Any associated energy and contamination costs must also be considered. These arise in the process of extracting, refining and purifying metals to manufacture the silicon wafers employed in the production of photovoltaic cells (section 5.3.2). The land space that solar panels would eventually use must also be regarded as an associated cost.

- In the case of biomass utilization (section 5.3.4), environmental costs will show through Life Cycle Assessment applied to the manufacturing of components for methanol (section 5.3.4.1) and ethanol (section 5.3.4.2) production, and to make boilers, turbines, generators, etc.

This calculation has probably already been made. If so, it will show that the cost of electricity produced by non-conventional sources is more than competitive when compared to that produced by conventional sources. However, this is not the point. From the standpoint of sustainability it is necessary to take into account the economics of a venture, although it is probably more important — especially at the present time — to put more emphasis on the environmental and social aspects of the business.

This means that **even if the cost of electricity generated by non-conventional sources were higher than that generated by conventional sources, society should go ahead at full speed and start phasing out the**

latter. In other words, policies should be implemented for the replacement of conventional sources by non-conventional ones **even if the cost per kWh is higher than in conventional plants.** This way, the conservation of the environment can take precedence over the economy, and people can still grow but through better development.
This is not news, and can be done. In the US some states are implementing the zero tolerance policy for car emissions. Their bylaws do not consider that this policy will mean a higher cost for purchasing a car. In other words, local authorities — quite rightly — deem that the environment and people's health are more important than economics. The same applies to energy generation.

Conventional energy plants have been working for more than a century with the purpose of bringing comfort and benefits to people, but mainly to make money; this is fine, since it is at the heart of the capitalist system, yet no attention has been paid to the environment, with results that are now here for everyone to see. Some progress has been made indeed, in the last decades of the 20th century, but unfortunately in some ways it looks like a case of being too little, too late.
Existing energy-generating plants that use coal and oil are deemed not sustainable not only because they use non-renewable fossil fuels, but because their emissions contribute to global warming — with its known effects on the world climate and the melting of the glaciers. Eventually, coal and oil reserves will be depleted and the world will have to find other energy sources.

Nuclear energy is also non-sustainable not only because it uses non-renewable and thereby finite resources, but mainly because of the already-discussed problem with radioactive wastes. One proposed solution is to encapsulate and bury radioactive wastes in deep caves, but it is only a temporary solution since there does not yet in existence a metallic enclosure that will prevent leaks over the long term, and because geological phenomena such as earthquakes can liberate such highly dangerous materials. One plan has even thought of burying such containers deep in the sea, but again, science has not yet produced any material that can resist corrosion for a thousand years. Perhaps energy generated by fusion provides some hope, but until now, after of decades of research, no solution is in sight.

Of course, there remains hydro energy, although the world is running out of adequate sites for these undertakings. Besides, large hydroelectric dams, which generate the cleanest source of conventional energy, usually provoke the loss of very large extensions of agricultural land, as well as erosion, climate change and social problems. They are also capital intensive and normally alter an area's ecology. The Aswan Dam is one example of this last: while producing considerable economic benefits for the Nile Valley, it deprives of nutrients the lands that lie downstream, requiring a larger use of

fertilizers. Meantime, the ecology and geography of the Nile Delta are changing. For instance, near the Rosetta Mouth of the river, there are no more of the sardines that once lived in the mud carried by the Nile. Severe coastal erosion has also resulted: the beach is being invaded by the sea, as no more sediments are carried by the river to resupply the seashore with sand.

From the social point of view, a large hydroelectric undertaking can produce disruption in the way of life of many people, as has happened at The Three Gorges Dam in China — which will displace more than one million people and flood countless villages and agricultural land. Naturally, huge economic benefits will be derived from the availability of cheap electricity in a poor area of China.

5.2 Brief technical information on energy conversion equipment

Production of electricity is usually a procedure that requires several steps taken in sequence, as follows:

5.2.1 Coal-fired, gas-fired or oil-fired power plants

Production of electricity is usually a procedure that requires several steps taken in sequence, as follows:

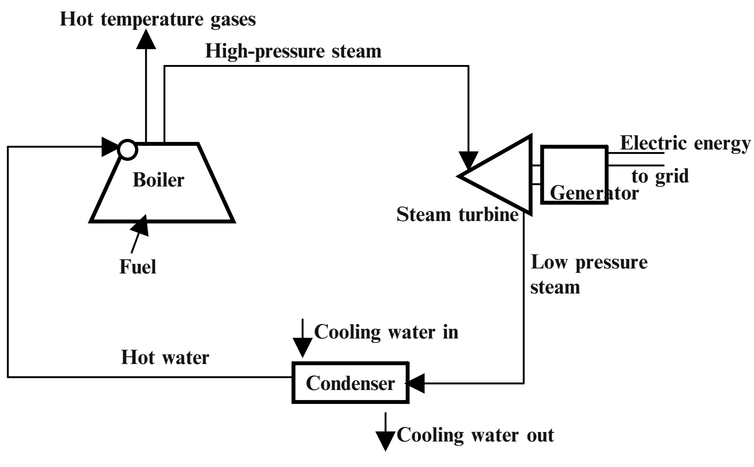

Figure 5.1 **Sketch of a coal-fired power plant**

5.2.2 Nuclear power plants

They work in a similar fashion:

- First stage: atoms split in a **reactor**, generating heat in the process; this is the equivalent of burning fuel;
- Second stage: Heat is transferred to an **intermediate fluid;**
- Third stage: This fluid transfers its caloric content to water in a **heat exchanger***,* producing steam, just as in a boiler;
- Fourth stage: Steam drives a prime mover, such as a **steam turbine**, which in turn drives an **electromagnetic rotor;**
- Fifth stage: The rotation of the rotor, which is part on an electric generator and within an electromagnetic field, generates electricity, which is then distributed through a grid.
- Fourth stage: Same as in the closed cycle described above.

5.2.3 Gas turbines

These work according to a different principle, since the combustion takes place within the machine, and not in another place, as occurs with boilers. The gas engine includes a gas turbine (the difference between a gas turbine and a steam turbine is that in the first, hot gases make it turn, whereas in the second case, steam makes the turbine rotate). When the gas turbine rotates, so does a compressor attached to the turbine shaft.
The process is as follows:

- Air is sucked out of the atmosphere and compressed in the **compressor**.
- The compressed air is sent to **combustion chambers** where fuel is injected, producing combustion and hot gases.
- The gas stream is directed against the blades of the turbine, making it rotate.
- A turbine-driven generator produces electric energy.

This cycle is open in the sense that, once burnt, the working fluid (hot gases) is discharged into the atmosphere.

5.2.4 Wind turbines

These use the wind's kinetic energy (which is a function of the wind's velocity). They usually consist of three large blades attached to a rotor that is connected to an electric generator through a gearbox. Wind impinges on the blades, thereby making them rotate and driving the electric generator.

5.2.5 Diesel engines

These engines utilize the stored chemical energy of diesel or gas. A diesel engine uses pistons that are displaced within cylinders in an alternating, lineal motion. A piece of equipment called a crankshaft, which is connected to an electric generator, converts the alternating motion into a rotatory one.
The engine sucks air from the atmosphere, compresses it within the cylinders by means of the pistons, and then injects pulverized fuel into the compression chamber, where the mix of air and fuel is ignited. This produces gases whose expansion result in the pistons' movement, as well as in motion by the crankshaft and the electric generator, which latter produces electricity. This is also an open-cycled process whose efficiency is better than that of steam turbines, while still being low: a large part of the fuel's energy is spent in mechanical friction, in heat losses in cooling the engine and in the exhaust gases.

5.2.6 Hydropower plants

Both small and large installations of these plants use hydro turbines (different types will suit a given site's characteristics). The turbine is attached to an electric generator, whose 'fuel' is the **potential energy** of the water — that is, the energy yielded by the height of the reservoir (head) where the water comes from — and the rate of the water's flow. Micro-hydro plants have outputs of up to 100 kW, while mini-hydro installations produce up to 1,000 kW.

5.2.7 Biomass

Energy from coal, gas, oil and wind comes from the sun, but we cannot utilize it directly, but must use an intermediate. The same is true about the energy one needs for living: it originates in the sun, but people cannot utilize it directly, but only through an intermediate — in this case, **plants.** The human body makes use of this energy when inhaling the oxygen they produce, and by ingesting the nutrients they contain.
The sun generates its own energy through a process called **nuclear fusion,** a process that scientists are trying to reproduce in laboratories, albeit without very much success to date.

By using energy from sunlight, water, and carbon dioxide (CO_2), a plant's chlorophyll enables it — through its green leaves — to convert the sun's energy into sugar and oxygen (O_2). O_2 is then a 'waste' or a by-product of this

process, which is called **photosynthesis**. The plant itself uses the balance of energy in order to grow, and it stores the surplus energy. See Figure 5.2.

Photosynthesis involves a reduction process — that is, it takes oxygen from the CO_2 molecule, and in so doing it absorbs energy from sunlight. When wood burns in the presence of oxygen, the process is reversed, since it is a process of oxidation that releases the energy absorbed in photosynthesis, as well as CO_2. As biomass consists of carbon and hydrogen, these components can be processed to give up a fuel known as biogas.

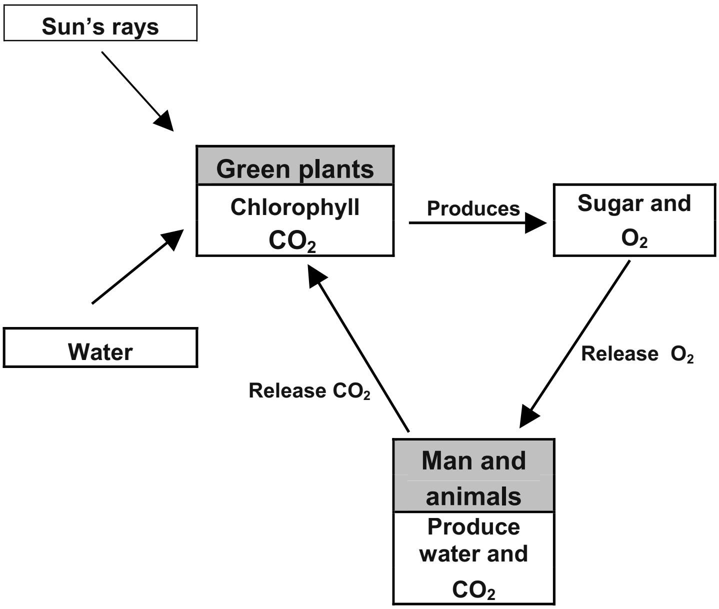

Figure 5.2 **The photosynthesis process**

One can see that in all these cases of energy production, some intermediate is necessary. Devices or prime movers are needed, including boilers, steam turbines, gas turbines, diesel engines, wind turbines, or hydro-turbines. But these devices merely extract the energy contained in various intermediaries: a fossil fuel, the wind or water (all of them of solar origin), to then generate electrical energy by driving a generator. This raises an obvious question: Is there any way to directly convert directly solar energy into electricity?

Yes, there is.

The only way one can directly convert solar energy into electricity is by employing the **photovoltaic effect** (section 5.3.2).

5.2.8 Geothermal

This section deals with both **ground-source heat pumps (GSHP),** for cooling or heating purposes, and with **geothermal energy**. The utilization of the former can drastically reduce electrical consumption, while the latter can be used for heating purposes and to generate electricity. Therefore, the concern about sustainability raises interest in their utilization.

5.2.8.1 Heat pumps

In order to understand how a heat pump works it is necessary to have an idea of how an air conditioning unit or fridge works, that is, of the refrigeration cycle. Both systems have the same elements: a compressor, a condenser, an evaporator, a valve called an expansion valve, and pipes connecting these elements (Figure 5.3). The expansion valve separates the two sides of the compressor: that with the high pressure (discharge, output) and the one at low pressure (intake, input)

A working fluid is also part of the system. This exists alternatively in a liquid and in a gaseous state (like the water and steam in the water steam cycle of Figure 5.1), and the entire cooling principle is based on this alternation. The fluid has a very low boiling point, i.e., it necessitates very little heat to evaporate, or to pass from the liquid state to the gas state (unlike water, which needs to be heated to 100°C to evaporate).
A liquid will evaporate by taking or absorbing heat **from** somewhere/something else.
For a gas to condensate requires giving or transferring heat **to** somewhere/something else.
Now it becomes clear just how the system works:

- The compressor compresses the refrigerant — which is in a gaseous state — at a relatively high pressure (1).
- The hot gas is piped to the condenser (2) where it condenses, i.e. becomes a liquid, delivering heat in the process. A fan takes air from the atmosphere, pumps it through the condenser and in so doing absorbs the heat from the refrigerant and discharges it into the atmosphere.
- After leaving the condenser, the liquid refrigerant reaches the expansion valve (3). Bear in mind that the expansion valve separates the two parts of the circuit. The high pressure is where the liquid is now. A small orifice in the expansion valve allows some of the liquid to enter the evaporator (4), which is held at a low pressure because of the suction produced by the compressor.

- Because the liquid is now at a low pressure it will quickly evaporate, thereby **taking heat from the area surrounding the evaporator** (which could be the interior of a fridge or of a car, or air that passes through the evaporator coming from a room).
- The refrigerant leaves the evaporator at a low temperature, and low-pressure gas is fed again into the compressor, to repeat the same cycle.

Note:

A simple experiment can be performed to check how low pressure makes for fast evaporation: Moisten the back of one hand, immediately raise to the mouth that damped area and inhale with the mouth. A cooling of the damped area will be felt immediately, which results from the vacuum or low pressure created by the suction that evaporates the humidity. This required taking some heat from somewhere, in this case the damp spot on the hand, which is thereby cooled.

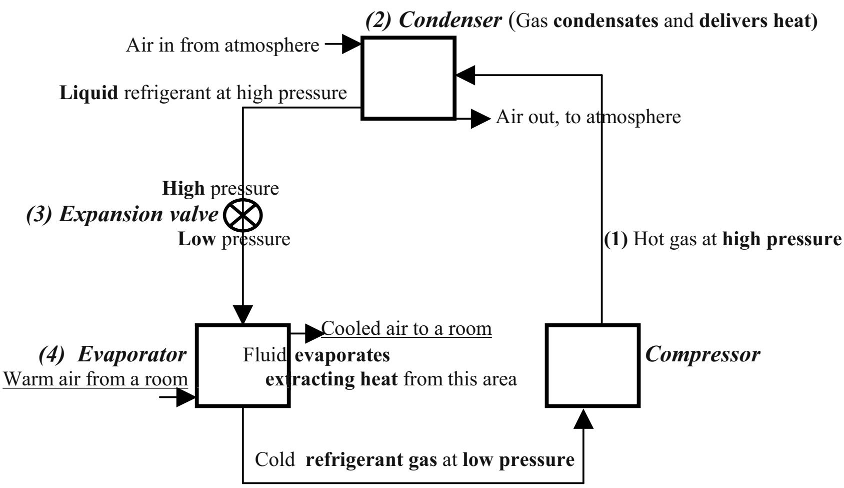

Figure 5.3 **Air conditioning cycle**

Heat pumps work through a simple concept that uses the system explained above, but one that can work in reverse: that is, it can be used for heating, instead of to cool.

This type of equipment usually involves placing the condenser and the compressor outdoors. The evaporator is situated indoors, along with the ducts that also provide heated air to a house. These are usually called **air-source heat pumps (ASHP),** because they use air as a medium for condensation (in summer) or for evaporation (in winter). In summer, the gas condenses using

the air as a cooling system (even it is hot outside), whereas in winter the liquid refrigerant evaporates, thereby taking heat from the air (even if it is cold outside).

This system (in both its versions) works well and has been installed in millions of houses around the world. Yet it is necessary to realize that it works in very unfavourable conditions, since it absorbs heat from a very cold environment (in winter), and discharges heat (in summer) to a very hot environment. The fact that this equipment has to work with variable outdoor conditions means:

- The Energy Efficiency Ratio (EEF), that is, the relationship between input and output, is affected by outdoor temperatures. In summer, the higher the outdoor temperature, the lower the efficiency. In winter, the lower it is, the lower the efficiency. This translates into more electrical consumption for the same output.

- The cooling effect is also affected by outdoor temperatures, since the higher the outdoor temperature in summer, the lower the cooling, and the reverse is true in winter.

- The efficiency of the system is also affected by debris or dirt in the condenser/evaporator.

- The noise produced by the condenser's fan can be annoying.

Because of these drawbacks, which translate in more energy consumption and in turn more CO_2 emissions, the impact on the environment can improved through the ground-source heat pumps, which is the object of this section.
This concept is again simple, as it involves using the ground as a transferring medium, instead of the air in the outdoor condenser/evaporator. In other words, the ground can be used to discharge heat in summer, or to provide heat in winter. This is because when solar energy hits the earth, although some of it is reflected energy still is absorbed and stored in the ground and in water (about 45 percent), which thereby act as heat accumulators. These heat sources can be tapped by an arrangement known as ground-source heat pumps.
To take advantage of the ground's thermal conditions, one need only bear in mind that its temperature is rather constant (between 12 and 16 degrees Celsius) at a depth of about 3 metres below the surface, excepting at very high latitudes.

Some brief technical information about how GSHP systems operate

Ground-source heat pumps (GSHP) consist in adding to the above mentioned ASHP a pipe, usually made out of plastic, which is buried in the ground, and in a form of a loop that is several meters long (perhaps 50 or 60) in a horizontal arrangement. This circuit is integrated with a water pump to circulate water within the coil and the condenser/evaporator. In the GSHP system, the compressor is kept indoors. The system has a reverse capacity in that the summertime condenser becomes an evaporator in the winter, while the summertime the evaporator (becomes a heater in winter.

Summer operation:
Water cooled by the ground's temperature in the looped pipe is pumped into the condenser, turning the refrigerant into a liquid. The air circulating through the evaporator is chilled once the liquid refrigerant evaporates, and is then sent through ducts to cool the indoor environment.

Winter operation:
Water in the looped pipe is heated by the ground's temperature and pumped to the evaporator (which in summer acts as a condenser), turning the refrigerant into a gas. The air circulating through the heater (which in summer acts as an evaporator) is warmed by this process, and then sent through ducts to heat the indoor environment.

In some applications, the loop is placed vertically through holes drilled to a depth of maybe 90 meters or more. This means that the system can be used effectively for large buildings within a congested downtown area by drilling a battery of wells that have enough depth.
The system described here uses water as cooling fluid, possibly with antifreeze and in a closed circuit — meaning that the water is constantly re-circulated. Other systems use open circuits, whereby water is extracted from a river, for instance, its thermal properties used, and then discharged back into the river.

Probably the largest office building in the world using this system is the Waterfront Office Building in Louisville, Kentucky, USA, completed in 1994. It has four 40-metre-deep wells, and uses an open circuit that discharges the water into the Ohio River. The Geothermal Heat Pump Consortium (see Internet references for Chapter 4) claims that the system's cost was US$1,500 per ton of refrigeration. By comparison, conventional systems with centrifugal chillers, cooling towers, and ancillary equipment, costs from US$2,000 to US$3,000/ton of refrigeration (see Glossary).

Economics

In summer, a conventional ASHP system needs to condensate the refrigerant using air at a temperature of, say, 32°C. Clearly, this compares poorly with a similar scenario using water at 12°C.

In winter, the evaporator must extract heat from outdoor air that could be at, say, 2°C or less, yet using groundwater it can extract heat from water at temperatures as high as about 11°C.

Some researchers (see azcentral.com, in Internet references for Chapter 5), say that a house with about 180 m^2 of floor space can be heated or cooled for as little as US$1/day. While this figure may appear to be low, there can be no doubt about the savings and their magnitude. The same source says that the initial investment of several thousand dollars can be recovered in 2 to 3 years, claiming that a 20- to 40-percent savings can be achieved against conventional units.

Sustainable sources (see Internet references for Chapter 5), claims that studies by the US's Environmental Protection Agency (EPA) indicate that these systems have the following increases in efficiency: See Table 5.1.

Table 5.1 **Comparison of efficiencies of GSHP against other sources**

Equipment type	Greater efficiency reached by GSHP
Gas furnaces	48 %
Oil furnaces	75 %
Air-source heat pumps	40 %

5.2.8.2 Geothermal energy

Another very powerful and inexhaustible source of heat is the thermal activity in the Earth's core. This is not a new discovery; the Lardarello geothermal plant in Italy — the first of its kind in the world for electricity generation — was commissioned exactly 100 years ago, in 1904, and is still generating.

How does it work?

Water and steam are sometimes trapped in some sort of reservoirs in the earth's crust due to geological formations. A well bored to that reservoir will bring very hot water and/or high-pressure steam surging to the surface. This water and/or steam can be used for heating purposes or for the generation of electricity through a steam turbine and electric generator — or it can be used for both purposes. Many geothermal plants are in operation around the world, such as in the US, Italy, France and Iceland. In this last, the capital Reykjavík probably has the largest application of district heating using geothermal

energy. Many thermal stations around the world, such as in Bath, England, or Budapest, Hungary, use geothermal water for leisure and curative purposes.

Different types of geothermal reservoirs exist in the earth's crust. Some produce pure steam, others produce only hot water, and yet others give rise to combinations of the two. If the water temperature is hot enough and at enough pressure, it will also generate steam when it is released to the surface. It does so because in the reservoir the water is under a greater pressure than that found on the earth's surface; as a result, when it releases at the much lower pressure, it evaporates into steam in a process called 'flashing'.

Advantages of geothermal plants:

- An inexhaustible source of energy and, as a consequence, sustainable;
- Produce heat and energy without polluting;
- Need little space to be developed, so are probably the most land-use effective option;
- Unaffected by rain or wind regimes, and operate 24 hours a day, 365 days per year.

Disadvantages of geothermal plants:

Although only distilled water is used in boilers, turbines and condensers, these are notorious for problems associated with water impurities. Thus, immediate concerns are raised regarding the dangers to the generation equipment under discussion, since they utilize geothermal steam and water that is rich with minerals, gases and impurities.
Sinclair Knight Merz Pty Ltd. (see Internet references for Chapter 5) indicates that maintenance costs for this type of equipment amount to about twice the usual cost for plants using fossil fuels, mainly because of these problems with corrosion, deposition and erosion.

Economics
It is difficult to establish values for geothermal plants because of the many factors involved, for instance, the need to drill new wells, when the yield of an exploited well is declining. 'Economy of geothermoelectric generation' (see Internet references for Chapter 5) provides very detailed calculations on this issue. See also Ian A. Thain (see Internet references for Chapter 5), for a brief but good description of problems with the Wairakei geothermal plant in New Zealand.

Society's options
Since energy sources are diminishing, common sense says that humankind should contemplate two different but complementary options:

- Reduce fossil fuel consumption in order to extend the life of existing reserves, not only by lessening the dependency in fossil fuels, but also by using them more efficiently.

- Switch to non-conventional sources.

The first option has been in force for decades, and now there are 'fuel-efficient' (at least by present standards) aircrafts and car engines, power plants and manufacturing processes. Even so, it appears that these advantages are offset by population growth, with its demand on services, and the consequent creation of more consumption.
Therefore, it is reasonable to think that society's options point to the second alternative, at least for the time being, to alleviate the load and demand on fossil fuels. Fortunately, serious attempts have been made by governments to switch partially to non-conventional sources of energy: countries such as the UK, Germany, Denmark, Spain, Austria, Canada, the Netherlands, Belgium, the US and India, to mention only the most advanced, have taken great strides toward using non-conventional sources of energy.

5.3 Non-conventional sources for energy generation

Several alternatives of non-conventional energy sources or renewable energy sources (RES) are available. What follows will include brief descriptions of each one, although readers are cautioned not to expect exhaustive accounts on each system: that would take up hundreds of pages while distorting the purpose of this book. This is not a technical manual, so this information will only be illustrative. This book's main purpose is to let readers know about both the existence and the potential of different non-conventional sources of energy generation. Information has been added, when it is available, to comment on the advantages and disadvantages of each system, their potential, some technical limitations, a brief word on the economics involved, and a few actual installations will illustrate the subject.

Although all the mentioned points are important, this last is especially significant to the aim of fostering sustainability, since it shows that these plants 'are not castles in the air' or far-fetched technologies that will take shape some time in the future. These technologies exist today, they are generating energy around the world, and they will probably be the key electricity sources of the future.

This book aims to give readers — researchers, policy makers, stakeholders or those implementing some new energy source within a community — an idea of the most suitable plant for their local need. To that end, of course, this author would also encourage consulting an advanced bibliography, some manufacturers and energy experts regarding their use. That is, the aim here is to furnish a starting point for such projects, and to help with a discussion about the options.

Two main reasons urge replacing non-renewable energy sources with renewable ones. One is that the world will eventually run out of coal, oil and gas, since of course reserves are limited. But even if new and richer oil and gas fields and carbon deposits were found, or if new techniques can improve extraction and combustion, the main problem is atmospheric pollution, especially with the production of CO_2 as a flue gas release, since it makes for climate change by increasing the greenhouse effect.

This is why the utilization of renewable sources is so important. To simply give a broad idea of the order of magnitude involved, bear in mind that calculations show that, to produce one GWh (see Glossary) of electricity, renewable energy plants generate an average of 6 metric tons of CO_2. Meantime, coal, gas and oil power stations produce **120 times more** than this much CO_2 per GWh.

5.3.1 Wind energy

Technical aspects

Something to think about

Only 2 percent of the sun's heat reaching the earth creates winds, building up kinetic energy. By using wind turbines, humanity converts it into electrical energy.

Enormous progress has been made in the area of harnessing this wind energy, which is centuries-old endeavour with the famous examples of Dutch and Spanish windmills, and water pumps operated by windmills on farms in many countries.

Modern technology utilizes the same principles yet through a completely different approach, namely, by using turbines with vertical and horizontal axes, and computer-assisted adjustments of these blades — which are as aerodynamically shaped as airplane wings. Many of these wind turbines dot the landscape in Germany, Denmark, The Netherlands, Austria, India, and elsewhere, as more than 20,000 wind turbines are now operating around the world.

Statistics show that Germany has the largest amount of installed wind power, followed by the US, Spain, Denmark and India — with a total output, as in the case of Germany, of thousands of megawatts. The second largest wind farm in the world is in King Mountain, Texas (see Internet references for Chapter 5); according to "*Globe Business*", July 2001, there will be 214 wind turbines with an installed generating capacity of 278 MW around the globe — which thus prevent the release of 20 million tons of CO_2 by substituting for fossil-fuel fired power plants.

The largest offshore wind park is located in the shallow waters off Middlegrunden, about 2 kilometres outside of Copenhagen. It involves 22 wind turbines placed in an arch, with their columns anchored at a depth of 3 to 5 meters. Each turbine is 63 meters tall, and has rotors of a 75-metre diameter. Wind turbines are usually mounted on conical steel or concrete towers of different heights (of an average of 50 metres), depending on the area and the output. Smaller wind turbines use a steel pole supported by guy wires.

The blades are attached to a shaft that drives an electric generator — usually through a gearbox — to increase the generator's rotatory speed.

The relationship between wind velocity and electrical output is **not linear** but **cubic**; that is, the energy produced increases proportionally to the cube of the wind's speed — which also means that reductions in wind speed also have a considerable effect on energy output. These devices are subject to the variable intensity of winds; consequently, electricity production is intermittent. However, this does not appear to be a problem because electricity from small units can be stored in lead-acid batteries, as DC (direct current), and since modern units can level off power produced at their rated capacity.

Wind turbines are usually assumed to have 20 years of life.

Wind energy depends of three factors: **wind speed, air density,** and **rotor area.**

The wind speed is a natural characteristic of a zone, so not all locations will suit this factor. Air density is directly linked to output: the denser the air, the better. Thus, care should be taken when considering locations at a high altitude, due to the thinner air. Rotor area depends, of course, on the length of the blades and the height of the tower to accommodate them.

Safety

The rotor ensemble has safety systems to brake or stop the unit when strong winds may imperil the structure, since the main safety problems have to do with excess speeds. For instance, if the generator for whatever reason disconnects from the grid, the absence of a load will tend to speed up the rotor to dangerous speeds. Hence, the necessity of installing automatic braking

systems. One of the systems simply changes the pitch of the blades, thereby stopping the rotation.

Economics of wind turbines

From the economic point of view, wind turbines are competitive with the producing energy from coal-fired power plants. Yet this comparison does not factor in the hidden costs of the latter — such as the depletion of fossil fuels, pollution, global warming (from the emission of CO_2), etc. As a result, it appears that wind turbines are economically more advantageous that even modern coal-fired power plants, once the environmental costs are considered. Wind turbines can generate electricity in some places at a cost as low as US$0.03 per kWh.

Different sizes of wind turbines are available on the market to suit different needs and conditions. In wind farms, it is customary to install large units producing as much as 1.8 MW to generate electricity to feed the grid.

Regarding investment costs, they vary widely depending on the size, winds, etc. For instance, offshore wind turbines can call for an investment of about €1,700 per kW, and large wind turbines, due to economies of scale, generate energy at a lower cost than smaller ones. Small turbines, rated from 1 kW to perhaps 100 kW, are adequate for household use but do not offer the benefits of economies of scale. Nevertheless, an economic calculation will probably show a little savings — say over a 20-year period — compared to using power from the grid, after considering all the expenses of purchasing the unit, its installation, more taxes paid because of a property's increased value, yet less taxes paid because of incentives, maintenance, insurance, etc. However, the most important part is the savings in fossil fuels, and in the air pollution produced if the electric utility supplied the household, instead of the wind turbine.

A wind turbine installed on a farm will probably generate an excess of energy. In such a case, it is possible to inject that excess into the grid, selling it to the power company. Many states in the US have provisions for such arrangements, and normal selling prices for that excess electricity produced on such farms is the same as the price for electricity bought from the electric company. The importance of wind turbines becomes evident when one considers that about 100 turbines, depending on an area's characteristics, can supply more than 75,000 homes. Because they work in a 'third dimension' — since they occupy no physical space other than for the tower and the service roads — the land where they stand can be used for other purposes as well.

Environmental aspects

Without doubt, these units bring considerable benefits in saving fossil fuels, and in the cost of their extraction, refining and transportation. They do not

pollute, even if some people claim that they contaminate a landscape visually. They are elegant structures, grouped in so-called **wind farms**, and if they alter the landscape, the same can be said of a bridge or a road. Other than this, they do not generate any type of pollution while offering opportunities for thousands of people to engage in their construction, erection, and maintenance.

Sustainable aspects

Wind turbines are a sustainable way of generating energy because they:

- Use an inexhaustible 'fuel': the wind.
- Are not polluting in any way, except during the manufacture of their parts.
- Substitute for fossil fuel consumption.
- Allow for electricity to exist in remote areas, thereby providing a better standard of living.
- Create jobs for thousands of people engaged in their manufacture, sale, installation and maintenance. It is said that the wind turbine industry creates 22 direct and indirect construction and manufacturing jobs for each MW of installed capacity, and wind projects create one operation and maintenance job for every MW of installed capacity (see *Renewable energy* — Internet references for Chapter 3).

Naturally, some noise is produced by the blades' movement, normally as a function of their speed, which could provoke complaints from neighbours. Countries such as the Netherlands, the UK, Sweden and Denmark have wind turbines installed offshore in shallow waters, eliminating the problem generated by noise.
Nevertheless, there is widespread agreement that the noise should not be more than 30 dB (see Glossary) at a distance of 350 meters; this is the level of noise of a quiet bedroom. To assess the intensity of discomfort that this noise could produce, as a comparison the noise level in an office is in the order of 55 dB.
In this connection, Wind Flow Technology Ltd. (see Internet references for Chapter 5) cites a survey done in Europe in the mid-90s on the annoyance factor of wind turbines in sixteen sites within three countries. Its main finding was that the number of people expressing annoyance by wind turbine was small. Complaints have also arisen, especially in California, about the thousands of birds killed by the rotating blades.

From the perspective of industrial ecology, it has been argued that wind turbines do not recover the energy that was employed to manufacture their constituent parts, for their erection and decommissioning. However, a Life Cycle Assessment (Appendix, section A.5) has shown that the energy spent is recovered within a couple of months.

As a bottom line, it appears that wind turbines constitute an efficient way to get renewable energy, and one hopes that the natural logic of ongoing technical progress will boost their efficiency even more.

5.3.2 Photovoltaics (PV)

Something to think about:

> *The amount of solar energy that hits the surface of the Earth every minute is greater than the total amount of energy that the world's human population consumes in a year.* (US National Renewable Energy Laboratory)

Edmond Becquerel discovered the photovoltaic effect in 1839, when he found that some substances exposed to light generate electricity. This phenomenon can now be seen in pocket calculators that are not battery operated.

Technical aspects

As mentioned previously, this is the only way to directly convert solar energy into electricity. Its foundation lies in Quantum Theory. Many are surprised to learn that Albert Einstein was awarded the Nobel Prize for Physics in 1921 "*…for his services to Theoretical Physics, and especially for his discovery of the law of the photovoltaic effect…*" — and not for his work on the Theory of Relativity.

In order to explain this complex issue in a simple and obviously very plain way, consider that the sun emits electromagnetic radiation, which Quantum Theory postulates as photons, which are understood as both waves and particles. When these photons impinge on photovoltaic material, they transfer energy to it and thereby produce the movement of electrons; this is electrical energy. The human body feels such transfers of energy in the form of heat, such that when we are exposed to the sun's rays, we get warm, while our unexposed parts feel no such warmth.

In the industrial production of electricity through solar energy, this is generated in cells that are arranged in modules, which in turn form arrays and are connected to the grid through a converter, whose name derives from the fact that it converts direct current (DC) produced by the photovoltaic (PV) array into alternate current (AC) in the grid.

Each cell is formed by a negative phosphorous-doped silicon layer and by a positive boron-doped silicon layer. However, this process demands large surfaces to produce sizable amounts of electricity, putting a toll on land use. It is estimated that about 1,400 square kilometres (that is, a square with about 37 km per side) are necessary to generate 1,000 MW.

Nevertheless, PV is extremely important and is a fundamental component of spatial crafts, probes and satellites, as it is the only source of electricity available in outer space. At present (2004), the efficiency of PV is quite low, about 14 percent. But reliable estimates affirm that by 2020 it will reach 20 percent. Direct 12 volts current generated in a PV array uses a DC-to-AC inverter for utilization in AC devices, and rising the 12 volts to standard 110 or 220 volts.
The unit of measure for a PV module's output is in Wp, which means 'peak power' — that is, the power that a module produces in watts when it is exposed to a radiation of about 1,000 watts per square metre, or the amount of energy delivered by the sun in summertime at about midday.

From the point of view of their construction and installation, PV installations have these characteristics:

- Panels can be installed on roofs in the form of flat roof tiles or shingles, as well as in other places where they do not use up land space.
- They can be used very effectively as a means of transportable energy, with panels mounted on trucks. Of course, the best examples of this transportability are the PVs installed on the satellites and probes sent to outer space.
- They are modular.
- No maintenance is needed since there are no moving parts; due to this, these systems are robust and have a long life, and are practically maintenance-free.

To increase the efficiency of PV installations, sunlight is concentrated by the use of parabolic optical devices equipped with a mechanical contraption to track the sun along its journey through the day. However, this can also build up excessive heat in the panels, and sometimes it is necessary to provide a cooling medium. The same can happen in hot regions when panels are installed on roofs, so there is a need for ventilation to keep them cool.
At present, there is an estimated total installed capacity of PV of about 3,000 MW.

Economics of photovoltaic
The price remains high, at around US$6/kW, but the forecast is for reductions to about US$2.5/kW, in constant dollars, by 2020. Besides, in many countries the use of PV leads to tax savings.
PVs are ideal to power lights and small appliances in rural homesteads, however, large photovoltaic installations exist around the world, in countries like Greece, the US, etc. Germany has installations in Hemau, Bavaria, which, since 2003, is the largest PV plant in the world. It produces enough electricity

to meet the needs of about 4,500 people. See relevant information on this plant in *World's largest solar power plant* (see Internet references for Chapter 5). This report affirms that the operator is promising a **very positive** return on investment (ROI) of about 7 percent, on an investment of €18.4 million.

Environmental aspects

PV does not produce any negative environmental effects by way of pollution to the air, land or water. It makes no noise, and does not consume any non-renewable resources. Its 'fuel' is an inexhaustible source: the sun.

Sustainable aspects

- PV probably offers the best deal for the environment among non-conventional sources, perhaps being challenged only by mini hydro power plants.
- It provides thousands of jobs for the construction and installation of solar panels.
- PV constitutes an ideal alternative for remote locations or as back-up systems when problems develop in the grid. For instance, when electrical service is interrupted by storms, falling poles, cable failures, sabotage, etc.
- In India, the Punjab Energy Development Agency (PEDA) has installed an array of solar panels to generate enough electricity to operate 50 water pumps. They extract water from a depth of 6 to 7 meters, supplying 140,000 litres of water per day: enough to irrigate between 2 and 3.2 hectares for most of the crops (PEDA, see Internet references for Chapter 5).

Disadvantages

- For large installations, its greatest drawback is probably related to land use since, as mentioned, they cover large spaces. However, they can also be installed in uninhabited, desert areas.
- As the system works with sunlight, on cloudy days the production is low, and it is nil at night.
- Electricity must be stored in bulky batteries.
- Since PV produces DC, AC appliances need inverters.

Section 5.3.2.1 discusses a large-scale housing project built between 1997 and 1999 in The Netherlands, that uses photovoltaics to generate 1 MW of electricity. It is highly recommended that the reader consult the website for

this undertaking. It contains abundant technical information along with full colour photographs that illustrate various aspects of the project.

Section 5.3.2.2 shows a similar arrangement but for a commercial use in a supermarket in Finland.

5.3.2.1 Case study: 1 MW decentralized and building integrated PV system in a new housing area, Amersfoort, the Netherlands

Data for this case study was taken from the publication "1 MW decentralized and building integrated PV system in a new housing area of Amersfoort. Case studies: Netherlands" (see Internet references for Chapter 5).

This case shows that large-scale housing projects integrating a PV system at the district level are feasible, and relates with the generation of 1 MW PV system involving 500 houses.

Readers are encouraged to consult the mentioned Web site to see with very clear pictures how PV panels were placed to form eaves that link many houses, and their placement in other parts of the buildings.

The arrangement not only fit in with a very pleasant and beautiful environment, but it used no land space. The total project cost amounted to €9,227,621, or €18,455 per house. The mentioned paper states that the cost of electricity is of €1.15 kWh.

This paper makes an important point by asserting that the project has shown that PV is a building component.

5.3.2.2 Case study: Solar modules made integral to hypermarket roof - Tampere, Finland

Data for this case study is taken from "Solar modules integrated into roof of hypermarket".

This renovation project of the Lielahti Citymarket in Tampere, in south Finland, involved installing solar panels on the building's roof, totalling 330 m^2, in order to produce about 39 kW of energy; this is sufficient to fulfil the needs of the market's shops.

This paper argues that a big advantage of the system is that in the

summertime, when the demand for cooling and air conditioning is at its peak (around midday), the electricity produced by the panel also peaks. In the summer, it will cover about 4 percent of total energy needs.

5.3.3 Solar collectors

Some of the energy received from the sun can be harnessed through photovoltaic devices (section 5.3.2) and by using heat collectors that heat water for different uses.

A solar collector is a simple gadget with a black metal plate that works as a solar heat absorber. Embedded in this plate is a metallic coil, and the whole ensemble is enclosed in a double glass cover. Let us explore the components of this collector:

The black metal serves a twofold purpose: as an absorber of sun energy and to support the metallic coils. Black surfaces catch the sun's energy well, as they do not reflect it. Quantum Mechanics theory explains this behaviour in terms of an interaction of electromagnetic waves from the sun with matter. This principle is used every day by people who wear dark clothing in winter, in order to absorb the sun's rays, and light apparel in the summer to reflect them.

The metallic coil conducts water, which is fed from its lower part, and discharges hot water through thermal convection (see Glossary) at its upper end. The heat collected by the black plate transfers to the water by conduction.

The glass enclosure has two purposes: First, it captures the infrared radiation (non-visible light) that enters the enclosures but cannot escape. This is the well-known greenhouse effect, which is described in any book on optics. It is also why the interior of a car that has shut windows and is left in a parking lot on a summer day is so hot that even its steering wheel cannot be handled.

The second purpose of the glass enclosure is to prevent the convection heat from dissipating into the atmosphere. This very principle is used to heat air, when it is forced to the bottom of the device and made to circulate upwards between the black plate and the enclosure. Heat is transferred by conduction from the black plate to the rising air.

For large industrial applications, the system works differently, since it employs mirrors. A project in the US called Solar II (see 'Solar thermal electricity', in Internet references for Chapter 5) involves 1,800 parabolic trough mirrors around a tall tower. The mirrors track the sun's movement and

reflect the energy received to the top of a central tower. This tower contains a molten salt solution that absorbs the energy and heats the water, generating steam; this steam drives a steam turbine, which in turn runs an electric generator. The molten salt stores the heat and keeps a high temperature of about 565°C; therefore, even after sunset steam can still be generated for some time using the molten salt's caloric content. As with other systems (see photovoltaic systems in section 5.3.2), peak production is at noon, coinciding with peak demand.

This report maintains that the solar plant will generate electricity for more than 350,000 homes, which is indeed a considerable use of solar energy. Some countries, such as India, are very well suited for solar energy, given the number of sunny days per year and the amount of energy in kWh/m^2 that is received annually due to their nearness to the Equator.

Economics
Solar heating in large installations and with concentrators can be very competitive.

5.3.4 Biomass

Biomass is organic matter produced by plants and animal wastes. As described in section 5.2.7, photosynthesis converts the sun's energy into sugar and O_2. Plants, in turn, transform this sugar into energy and store it as starch. When people or animals eat plants and breathe O_2, this energy is transferred, used by the organisms, and any balance is eliminated as waste and as CO_2.
By the same token, when firewood burns the energy stored in that wood is released, together with CO_2. However, plants absorb that CO_2 again, repeating the cycle, so there is no release of additional CO_2 into the atmosphere. This is the 'carbon cycle' defined in section 2.7.

Not all biomass is in a solid state, since some residues, such as the black liquors from the paper industry, sewage sludge and sludge from other industrial processes, are liquids. By 1990, the use of biomass worldwide accounted for 13 percent of total generated energy, although this figure conceals a great discrepancy between developed countries, which use only 3 percent, and developing countries, with 33 percent.

Types of biomass
Different types of biomass are wood, forest waste, crop residues, municipal waste, some industrial wastes, some grains, etc. It is also possible to utilize sawdust, peanut shells, bagasse, rice hulls, walnut shells, etc. Biomass is utilized to produce electricity by means of these devices:

Use by direct combustion
This involves the direct combustion of biomass in boilers to generate steam for industrial purposes, or to propel a turbine for electric generation. One example is the burning of bagasse — a sugarcane waste — in sugar mills.

Use by gasification
As we are about to see, it is possible to obtain the fuel **methanol —** which is used for cars or even in a blend with gasoline — by means of crop wastes, wood and wood wastes, animal waste, and many other 'wastes', such as from food processing.

5.3.4.1 Methanol

This is obtained from feedstock — a raw material containing carbon and hydrogen — through a process called **gasification** and through **steam reforming.** It involves subjecting the raw material to a high temperature and pressure, and purifying it to obtain a synthetic gas called 'syngas', a mixture of carbon monoxide and oxygen. Because its source is a renewable resource, this is a **sustainable fuel**. A ton of feedstock can produce about 700 litres of methanol. Bagasse, for instance, is an excellent feedstock for methanol, because of which countries like Brazil and Cuba are able to drastically curtail their dependence on fossil fuels.

After eliminating undesirable gases and impurities from syngas, a catalytic process leads to obtaining methanol. The advantage of producing methanol is that it permits the use of feedstock of many kinds, such as waste from industries, forestry, municipal wastes, etc.
Methanol is an alcohol, a biofuel, and its utilization does not add any CO_2 to the atmosphere, since the process returns the CO_2 that was taken earlier during the chlorophyll transformation in green plants, so it closes the energy chain.

However, methanol synthesis generates high amounts of CO_2, discharging it into the atmosphere. This implies a low efficiency in methanol production; nevertheless, it is possible to achieve high methanol production rates by the injection of hydrogen, but this requires high investment costs. This is why an integrated process with pulp-making makes for higher efficiency.

5.3.4.2 Ethanol

This is another fuel made by a process of fermentation of starch or sugar from sugarcane, and it is also obtainable from wood. The biological process produces a gas, which includes methane, carbon dioxide (CO_2), and water vapour. However, and because it is in competition with the production of food products, its price is not competitive enough to be used in cars. Besides, ethanol derived from corn cannot be considered sustainable because it uses limited resources.

Besides their uses as fuels, Ethanol and Methanol are attractive alternatives for vehicles operated by PEM (Proton Exchange Membrane) fuel cells (section 5.3.5). In a PEM cell, hydrogen and oxygen are mixed, and the result is electricity and water. These cells utilize hydrogen, but as this is a very flammable product to store it is better to have it in some carrier such as ethanol and methanol.

5.3.4.3 Biodiesel

Another fuel made from oils and fats that can substitute for or be blended with diesel oil is biodiesel. Brazil is one of the countries promoting its use as a fuel: recently, in December 2003, it planned to start using biodiesel for railway locomotives, in a proportion of 20 percent biodiesel to 80 percent diesel fuel. Biodiesel can be made from any vegetable oil, although in this case it will be made from soya beans since Brazil is one of the world's largest producers of this crop.

5.3.4.4 Methane

This is a flammable gas obtained from landfills due to the anaerobic (see Glossary) digestion of waste. Landfills account for more than 1/3 of methane emissions, making this very important especially since this gas produces the greenhouse effect (global warming) far more that the other gas that is responsible for the greenhouse effect: CO_2. Landfill gas is seldom pure methane, but it is made up of about 50 percent methane (CH_4) and 45 percent carbon dioxide (CO_2)

Besides, being a flammable gas, methane can generate electricity when burnt in a gas engine to drive an electric generator. This is clearly a **sustainable resource** since it comes from an inexhaustible source: waste. The benefits of this kind of utilization are as follows:

- It reduces the emission of methane into the atmosphere.

- Generates electricity.
- Replaces the use of fossil fuels.
- Burns cleaner than fossil fuels, even if not as efficiently as natural gas.
- Wind energy, photovoltaics and solar energy (as shown elsewhere in this chapter) are unavailable through the 24-hour day, due to intermittent winds and as solar devices only work in the daytime. This is not a problem with landfill methane, which is always available.
- It is the only non-conventional energy resource whose elimination leads to a benefit, as mentioned.
- Its utilization also reduces the danger of landfill fires.

Gyungae Ha, a Korean corporation (see Internet references for Chapter 5), extracts methane from a landfill and utilizes it to fire a boiler. The firm calculates that the use of this free fuel produces a savings of US$3,400,000, considering the market value of methane, and that it will greatly improve the air quality by curtailing the landfill's methane emissions, as well as by reducing 84,000 tons/year of CO_2.

Farm animals generate a considerable quantity of wastes. For instance, a pig generates 2.5 times more waste than humans, and producing methane. Besides, the wastes that materialize in cow, pig and poultry manure contain large quantities of nutrients that rains transport to rivers, which favours the growth of algae — depriving fish of needed oxygen. This is a strong reason to process manure. Overall, manure can have a dual application, as fertilizer or utilized to produce methane.

The decomposition of manure process methane. Dung or manure from farm animals, such as pigs, is usually collected in trays below the pigpens' grates, where it is stored in hermetic tanks called digesters. There, an anaerobic (or airless) decomposition takes place, producing biogas, which is piped to storage tanks for further use as fuel in boilers to generate steam. In turn, this steam drives a steam turbine electric generator.

In Canada, a plant to treat manure and obtain biogas has been built in Vegreville, Alberta (see EnviroZine, in Internet references for Chapter 5): the processed manure from 7,500 head of cattle will be used to produce electricity as of June, 2004. This manure is expected to generate 1 MW of electricity, and the plan is to increase this to 3 MW: enough to supply power to a town of 5,000. There is also an integral use of the waste since the liquid resulting from the process will be treated to get rid of ammonia, and, after adjusting its pH (see Glossary), it will be utilized for crop irrigation. Without a doubt, this is a very sustainable project. It is worth citing what the report says about the 'waste': *"This new **technology treats cattle manure as a resource as opposed***

***to a waste**. It is a new and very cost-effective approach that addresses social, economic, and environmental issues associated with manure management".*

According to David Hall (see Internet references for Chapter 5), in Norfolk, UK, the largest biomass plant in Europe is already in operation, producing enough energy to power 70,000 houses. It burns poultry litter — a blend of straw, wood chippings and poultry droppings — and, together with another two smaller plants owned by the same company, these the only plants in the world that operate with this 'fuel'. They have the added advantage of also producing as a residue a fertilizer that is rich in phosphates and potassium.

5.3.4.5 Pyrolisis

Pyrolisis occurs when waste is heated without the presence of oxygen. This process yields gas, liquid fuel and char. These residues can all be processed, refined, and used as fuels. Engines or boilers can use the resulting gas and oil, and the char can be gasified. One example of pyrolisis on a large scale occurred in the tire fire mentioned in section 2.12.5, where thousands of tires burnt without oxygen, producing oil.

5.3.5 Fuel cells

It appears that the future for fuel cells is brilliant. The ceramics industry (see Internet references for Chapter 5) forecasts a market of US$95 billion for fuel cell technology.
These devices can operate many appliances, from laptops and cellular phones to large generating plants. Naturally, it is not possible to operate such a broad range of applications with a single type of fuel cell. Table 5.2 gives a glimpse of types, applications and other characteristics of fuel cells. Whatever the type, the operating principle is common to them all. Many different sources such as methanol, natural gas, methane, etc., are used to feed fuel cells, while oxygen is taken from the atmosphere. They produce electricity, heat, and most of them issue pure hot water, so their contribution to pollution is nearly nil.

A common battery generates electricity due to a chemical reaction, and when the chemical materials are spent or saturated the production of energy ends, and they require to be replaced or recharged (when they are rechargeable). Fuel cells, by contrast, do not need any replacement or recharging, and will work as long as they have fuel, which is hydrogen in its different forms. Fuel cells actually consist of the reverse mechanism of water electrolysis. An electrolytic process involves two electrodes, called an anode and a cathode, immersed in water, and when electric power is applied to these

electrodes, the water separates into its two components: hydrogen and oxygen.

In a fuel cell, the system consumes hydrogen and oxygen and produces electricity, plus hot water. How does it work?
A fuel cell (Figure 5.4) also has two electrodes also called anode and cathode. Hydrogen is injected into grooves built into the anode, and oxygen is fed into grooves in the cathode. Between these two electrodes, there is an electrolyte (see Glossary), which can be solid, liquid or aqueous, that is made of various chemical elements. The electrolyte can be contained in a matrix or in a membrane. Generally, a catalyst, which is an element, or substance that accelerates a chemical reaction, coats both sides of this matrix.

Hydrogen is the simplest atom, having a proton as a nucleus, with a positive charge, and a single electron orbiting the nucleus has a negative charge. When hydrogen is fed to the fuel cell (left electrode in Figure 5.4), the catalyst, which is usually made of platinum (Pt), produces the separation or ionization of the hydrogen atom. Remember that an ion is an atom, which has either gained or lost electrons.
Since the catalyst separates the electron from the proton, there are now two ions, the positive being called a cation (H^+), and it migrates to the cathode through the electrolytic solution. The negative ion, the anion, is the free electron (e^-) in a continuous flow, and constitutes the electric current, and it goes to the cathode through an electric circuit and can be used to produce work, such lighting an electric lamp.

The cation from the electrolyte, the anion after doing work, and oxygen from the atmosphere, all meet in the cathode. There, the catalyst helps maintain a reaction that will produce hot water. It is possible to use this pure hot water for different purposes; in some cells, it is recycled to release hydrogen and recommence the cycle.

5.3.5.1 The fuel cell in automobiles

Nicolas Otto invented the combustion engine in 1875, and applied it to a motor bike; later, Gottlieb Daimler and Wilhelm Maybach developed an advanced gas engine. Then, in 1885, Karl Benz (the name is perhaps recognizable) built the first practical automobile in history.
The automobile was seen as a curiosity when it arrived at the end of the 19th century: nobody seriously thought that that smelly, noisy and uncomfortable contraption would replace the horse and the horse-drawn carriage of the time. Of course, the automobile brought a revolution in transportation, and from then on, nothing was ever the same.

Table 5.2 **Comparison between different types of fuel cells**

Type of fuel cell	Type of electrolyte	Catalyst	Output range	Operating temperatures (in degrees C)	Main applications	Efficiency (%)
PAFC	Phosphoric acid	Platinum	Up to 200 kW	150 - 200	Stationary	40-50
PEM (Proton Exchange Membrane)	Poly-perfluorosulphonic acid	Platinum	50 – 250 kW	80	Cars, Houses	35 - 40
MCFC (Molten carbonate)	Liquid solution of lithium, sodium or potassium carbonate		10 kW – 2 MW	650	Stationary	50 – 55
SOF (Solid oxide)	Solid zirconium oxide with traces of yttrium		100 – 200 kW	1000	Power houses Housing	45-55
AFC (Alkaline)	Aqueous solution of alkaline potassium hydroxide		5kW			70
DMFC (Direct methanol fuel cells)	Polymer membrane			50-100	Very small and mid-size applications, such as cell phones.	40
Regenerative						

Source: This Table was prepared with information from Breakthrough Technologies Institute/Fuel Cells 2000 (see Internet references for Chapter 5)

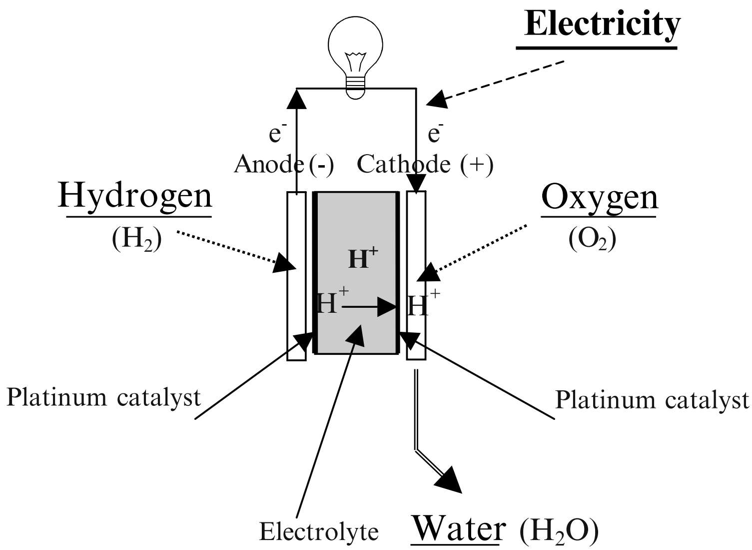

Figure 5.4 **Diagram of a fuel cell (PEM)**

At present (2004) humankind is at a similar crossroads regarding the imminent replacement of the familiar four-stroke gas engine running cars with a completely new concept: the fuel cell engine. Yet a difference exists, in that people at every level of society acknowledge that the air in cities has become difficult and even dangerous to breathe, that the noise is becoming intolerable, and that fuel costs are becoming prohibitive. Given this, and unlike a century ago, we are now looking at the future, at least in personal urban transportation. It is highly likely that in 20 years' time people will look back and wonder how we could cope with the situation that exists today.

From a technical point of view, this transformation has parallels. The steam locomotive served us well, but then the diesel engine phased it out, and the electric train, in turn, is replacing it as well. Ships were one of the first users of reciprocating steam engines, until fairly recently: the Titanic had two reciprocating steam engines and a steam turbine, using the steam discharge from the former. Steam turbines replaced the steam engines and, in turn, gas turbines substituted steam turbines.
In industry, large food-related industries started with huge reciprocating engines to drive their cooling compressors, to be replaced by steam turbines. In transportation, gas engines propelled aircrafts until the advent of the gas turbine.

All of these large users of primer movers have two common denominators: they use reciprocating engines, and rotating engines replaced them. The advantages of this change are considerable, especially from the point of view of reliability and efficiency. Reciprocating engines have hundreds of moving parts, and change direction constantly: they reach the top of the cylinder, then stop, accelerate until reaching the other end of the cylinder, stop again, then accelerate again, and so on, thousands of times each minute. The rotating engine, whether a turbine or an electric motor, has only one continuous movement, which is rotation.

Without a doubt then, the replacement for the reciprocating gasoline engine of a car should be a rotating one (that is, an electric motor), and the fuel cell will help reach this goal. Unlike the reciprocating engine's operation, this one is very simple: the fuel cell generates electricity that powers an electric motor driving the wheels, and that is it. Interestingly, the first automobiles back in 1888 were electric ones, and battery operated, but they did not survive because of the battery technology available at that time. Electric cars builders then did not heed environmental concerns, but did keep an eye on the price of fuel, which meant that the gas engine came to prevail.

All fuel cells work according the principle sketched out in Figure 5.4. The differences lie in the way that the hydrogen is injected, and in the composition of the electrolyte. It is thus worthwhile to perform a brief analysis of the different alternatives and options that fuel cells offer. Naturally, one important factor to consider is each system's efficiency, in other words, how much, in percentages, of the fuel injected into an engine turns into useful work. This calculation is not difficult, although since this subject is being analysed from the viewpoint of sustainability, it may be worth remembering that computations of efficiency need to consider the entire process.

For instance, gas-engine efficiency is measured according to the ratio between the injected fuel's energy and its output, but one is not considering here the energy needed to extract the oil, to refine and transport it, and to sell the fuel — let alone any environmental costs. In short, the whole process or cycle must be considered. Of course, the same applies to batteries or to fuel cells. Nevertheless, the data consigned in Table 5.2 refers only to fuel cells without considering the energy spent in their production, and without co-generation.

Latest concerns about fuel cells for automobiles

Comparing the environmental impact of the different types of fuels and engines requires considering their full cycles: that is, from the source, whatever it might be, to the wheels of a car, bus or truck. This is why it is

sometimes called the 'well-to-wheels' cycle, which can be divided into two: the process to put fuel in the tank (the source-to-tank cycle), and the process to make the wheels rotate and the vehicle move (tank-to-wheels cycle).

The efficiency of fuel cells in the second cycle by far surpasses that of the gas engine, because it loses heat in the tail pipe, in cooling the engine, and energy through friction because of all the moving parts.
There is also to consider loss of efficiency in the combustion process and more losses to operate valves, drive pumps, etc. This is an unquestionable advantage of fuel cells. However, when the source-to-tank cycle is considered some researchers, such as Wald (2004), believe that the convenience is not so considerable, and that drivers will end up putting more CO_2 into the atmosphere. To understand this it is necessary to take into account that all fuels exist in nature in the form of fossil fuels (carbon, oil and gas) and biomass, and the same applies to what can be called 'fuels' such as wind, hydro, PV, methanol, ethanol, etc. Fuel cells work, as seen, ionizing hydrogen, so hydrogen is considered a fuel despite a difference when compared to other fuels, *viz*., that hydrogen does not exist in a free state in nature, and has to be manufactured; this is where the problems arise.

To manufacture hydrogen some fuel has to be used, such as electricity for electrolysis, or methanol or natural gas, or electricity generated by the wind or sun. However, some researchers believe that these fuels could be better used to generate electricity for the grid, instead of to generate hydrogen for cars. Why is this?

Because, if for instance natural gas is used for hydrogen production, more coal has to be burned in boilers to compensate for the absented use of natural gas to generate electricity; and, since coal produces a high content of CO_2 in the flue gas, that content is indirectly attributable to fuel cells.

Different kinds of fuel cells
As mentioned, there are different types of fuel cells in various stages of development. In general, each of them is appropriate for some specific use/s. To provide just an idea, here is a brief explanation:

5.3.5.2 PAFC – Phosphoric acid fuel cell

It has a good output of up to 200 kW, and is used in small stationary power stations; however, they are not suitable for cars as they take some time to warm up. The system needs **pure hydrogen and oxygen**, which could be a drawback.

Actual installations: Holcomb, *et al*. (see Internet references for Chapter 5) provide details for installing a PAFC in the US, where there are 30 operating units. This fuel cell is supposedly the only available commercial fuel cell.

5.3.5.3 PEM – Proton exchange membrane

It has an output between 50 and 250 kW, and is ideal for mobile uses such as cars, trucks, as well as in houses. The system needs **pure hydrogen**, which could be a drawback.
Actual installations: In October 1999, a transit bus rode in Vancouver, Canada, equipped with this technology, and on May 2003, the city of Madrid received its first PEM powered bus, equipped with a 205 kW Ballard fuel cell engine.
Another 10 European cities will receive similar units, and the buses will refuel from 10 hydrogen-refilling stations. At present, most carmakers are considering this technology.

5.3.5.4 MCFC – Molten carbonate

Output ranges between 10 kW to 200 KW, which is appropriate for powerhouses. The hot water produced, due to the high operating temperature, can be used as steam to drive a turbine generator. On the other hand, because the high temperatures involved there is no necessity for expensive catalysis materials. It has the **highest efficiency of all fuel cells,** and the system is carbon monoxide tolerant, which means that it is not necessary to use very pure hydrogen.
Actual installations: An estimate put in about 700 the number of large plants installed all around the world, being Japan a leader in this field, as well as the USA. In Europe, the most important market is Germany.

5.3.5.5 SOFC – Solid oxide

Output ranges between 100 and 200 kW, which is appropriate for powerhouses as well as housing. It operates at a high temperature; therefore, the generated steam can be used for co-generation with a steam turbine driving an electrical generator. One of its main advantages is that it can **operate with different fuels** such as natural gas, alcohol, diesel, etc. It is not appropriate for car engines because there is a delay in reaching its working temperature.
Actual installations: De Guire (see Internet references for Chapter 5), reports that Siemens Westinghouse planned to have its fully operational tubular fuel

cell plant by October 2003. She also reports that in Australia planar units have been in operation since 2001. It is interesting to quote that SOFC fuel cells for residential use have a cost between US$ 500 and 1,500 per kW, with a payback period of about 4 - 5 years.

5.3.5.6 AFC – Alkaline

This is indeed old technology, but also the system that enabled space missions since the 1960s and it is still used in the Space Shuttle. It requires pure hydrogen and oxygen and is expensive. Its output is about 5kW with a relatively low operating temperature of between 150 to 200 ° C.
Actual installations: On London's streets can be seen an experimental hybrid taxi equipped with this technology. This vehicle offers the Holy Grail of zero emissions.

5.3.5.7 DMFC – Direct methanol fuel cells

As it name suggests this fuel cell utilizes methanol (section 5.3.4.1) as the source of energy. The technology is relatively new and it is still in its early stages, however the potential is tremendous and highly sustainable since it uses a fuel derived from vegetable wastes. In this way, the technology can solve two problems at the same time that is to get rid of the 'waste', and to generate electricity. As commented, there are fuel cells that need pure hydrogen. However, there are others that can use a hydrogen carrier and then extract the hydrogen from it, using an element called a fuel 'reformer' (see Glossary). One advantage of the DMFC is that it can eliminate the fuel reformer, increasing the efficiency of the unit.

Extremely attractive is the fact that this system allows the manufacture of tiny fuel cells than can be used for small applications such as laptops, camcorders, digital cameras, and mobile cellular phones. As guessed, the race to produce these micro fuel cells has already started, mainly in Germany and in Japan, and a company is planning to have 100,000 units in the market by 2004. Of course, there will not be something like recharging a battery. Instead, a small methanol cartridge will snap into the unit.

The Register (see Internet references for Chapter 5), reported on December 2003 that Hitachi will market a fuel cell the size of an AA battery to be used for PDAs. (see Glossary). The company claims that this device will have enough energy to power a hand held device for six to eight hours. Interesting, the water produced in the reaction is used to dilute the fuel down

to a concentration of 3 to 6 per cent. Toshiba, as expected, is also in the race but for the notebook computer market.

5.3.5.8 Regenerative

This fuel cell is still in the research stage. An interesting characteristic is that the fuel cell works in a close circuit, that is, the water produced in the electrochemical reaction is further electrolysed to obtain hydrogen. Therefore, these fuel cells have a dual function, as an electric generator and as an electrolysis cell.

A word of caution.
Different options and alternatives available for the utilization of non-conventional energy sources have been analysed. Most of then can probably be applied in an area, however, it is necessary to know the potential of the area for a particular undertaking. It is not realistic to think that an area is apt for everything since it is hard to believe that there is sufficient wind to install a wind farm, and at the same time plenty creeks and rivers with the adequate water flow for hydro, and also enough sun and bright days for PV, etc.

Consequently, it is deemed necessary to make an appraisal to determine the physical characteristics of an area regarding frequency and speed of winds, water flow, biomass generation, etc, and then use the most appropriate methodology. In addition, it is imperative to consider two another factors: the scale of the undertaking and the distance that the energy has to be transported. The scale of the undertaking is important for reasons of economies of scale (see Glossary), and the second because the inherent costs of construction a transmission line and the energy losses along the line.

5.3.6 The sea as a source of energy

There are different methods for using the energy available in the sea, and produced by two diverse effects, however this book only considers those that **have been built and are at present in commercial operation**. The main forms are **tidal energy** that works with the flow and ebb of the tides and **wave energy** that takes advantage of the kinetic energy of waves.

Needless to say, tidal energy is only possible where large tidal ranges exist. Most places have ranges about 7 to 8 meters, but in Canada for instance; the range is between 10 and 12.5 meters. Main places in the world for tidal energy are in Argentina, Australia, Canada, India, Mexico, Russia, South Korea, U.K., and USA. Only one tidal electric generation plant exists in North

America, and it is located in Annapolis Royal, Canada, taking advantage of the tide in the Bay of Fundy, the largest tidal range in the world. Commissioned in 1984 it has an output of 20 MW.

Tidal energy – The Rance tidal power plant

In this case, a barrage, that is a dam, is built with tunnels that allow water from high tide to enter a reservoir behind the dam, and in so doing, operating a hydraulic turbine. In low tide, the process reverses and water form the reservoir flows through the same turbine towards the sea. An electric generator attached to the turbine, generates electric energy. The drawback of this type of scheme is that only it works during the tides movement in both directions.

The most remarkable example of this type of generation is the Rance tidal power plant in northern France, which was commissioned in 1966. It has a 330 meters barrage, and a capacity of 10 MW, generated by 24 axial turbines with variable pitch, allowing them to work in both directions (water to the estuary in high tide, and water to the sea in low tide). Naturally, at a certain moment during high tide the level of the reservoir and the tide almost tally, therefore there is little transfer of water, and for that reason the turbines are made to work as pumps sucking water from the sea and discharging into the reservoir, and thus increasing the energy produced when the reservoir discharges into the sea.

There are also projects to utilize underwater currents using turbines as those found in a wind farm (section 5.2.4). In this case, towers are built on the sea floor and each one with two underwater turbines.

Wave energy – The Inverness wave power plant

In this type of engine, the kinetic energy of waves produces the rise and fall of a column of water within a conduit, which is connected with the open sea at its bottom. This column of water acts like a hydraulic piston, since during the rise, the water column compresses air above it, and this air is then used to drive a Wells turbine generator (see Glossary). During the fall of water, the water column sucks air, which is again used to drive the turbine, since it can work in both directions.

Therefore, in one instant, the waves raising the water column, creates a high pressure in the air above it and at the next moment, when the wave recedes, the water column lowers, and then sucks air. The air is then alternatively compressed and decompressed, by this oscillating water column (OWC).

An example of this type of pneumatic turbine is the Limpet plant, located in Inverness, Scotland, which was connected in November 2000 to the UK's

national grid. The plant is located in the Scottish island of Islay, and according to the Press Release Network, it has a pair of contra-rotating Wells turbines producing 250 kW each. See also “Sciences News” in Internet references for Chapter 5.

The International Energy Agency (IEA) in Paris has published in Internet the ALEP Guidebook (ALEP stands for Advanced Local Energy Planning) (see Internet references for Chapter 5). This document supplies very useful and comprehensive information about energy issues. For instance in http://www.iea-alep.pz.cnr.it/4_Summary.htm, Table 1 depicts an extensive listing of modes to use for planning and analysis purposes and related with energy.

In compliance with the idea already exposed at the beginning of this section that only installed and in operation renewable energy sources would be commented, only two modes of energy from the sea have been mentioned, tidal and wave energy. However, there exist various different schemes to take advantage of the thermal and mechanical energy of the seas. Some of the schemes proposed, are:

- Using the energy of the waves. A device bobbing in the surface, connected to a buoyant platform, can produce electric energy to operate pumps and turbines;

- Using the difference in temperatures in tropical areas and between lower and upper layers of water. Ocean Thermal Energy Conversion (OTEC). There have been feasibility studies made in many countries about this methodology, which first test took place in Cuba in 1929. A good place to get information is http://www.worldenergy.org/wec-geis/publications/reports/ser/ocean/ocean.asp

- Lately, there is research going on to utilize the energy contained in organic matter on the sea floor, when gas methane is released and mixes with salt water to create **methane hydrate**. There is an enormous potential from this source of energy, and some people believe that the available energy is more than twice the energy of all fossil fuels combined. The technology is expected to take about 15 to 20 years to be developed for commercial applications.

Internet references for Chapter 5

Noise from wind turbines

Source: Department of Trade and Industry, U.K. Government - Noise Working Group, Harwell. U.K. (2003)
Title: *Renewable energy*
Comment: Very comprehensive technical report.
Address:
http://www.dti.gov.uk/energy/renewables/publications/noiseassessment.shtml

Source: Australia Wind Energy Association (AUSWEA)
Title: *Wind farms and noise*
Address:
http://www.thewind.info/downloads/noise.pdf

Source: Danish Wind Industry Association (2003)
Title: *The energy in the wind: Air density and rotor area*
Comment**:** Comprehensive report in four languages including FAQ (Frequent Asked Questions).
Address:
http://www.windpower.org/en/tour/wres/enerwind.htm
Title: *Renewable energy – Benefiting Minnesota's economic long-term* (2002)
Address:
http://www.mnproject.org/pdf/Renewable%20Energy.pdf

Source: California Energy Commission (2002)
Authors: Dora Yen Nakafuji, Juan Guzman, and Guillermo Herrejon
Comment: This comprehensive report (70 pages) contains valuable information about equipment for and working conditions on large wind generators in five different areas, as well as for small wind generation. It provides information about the physical characteristics of the different types of turbines used. Figure 5.2 of this report is remarkable in showing an almost parabolic growth of energy produced by wind turbines between 1985 and 2001. Another chart shows the evolution of the capacity factor, a measure of efficiency of over 20 percent. There is a very illustrative comment by the authors to the effect that California has more than 10,700 wind turbines, and that the topography of the primary wind resources in California consists of narrow mountain passes leading into hot valleys. There are maps showing the location of these turbines throughout California.
A visit to this site is highly recommended.

Title: *Wind performance report summary (2000-2001)*
Address:
http://www.energy.ca.gov/reports/2003-01-17_500-02-034F.PDF

Author: Gyungae Ha – Korea Emergency Management Corporation.
Title: *Ulsan landfill methane as project*
Address:
http://www.pi.energy.gov/pdf/library/EWSL/EWSLkorea.pdf

Author: Environment Canada – EnviroZone, issue 38 (2003)
Title: *Turning animal waste into electricity*
Comment: On conversion of manure into heat, electricity, fertilizers, and reusable water. This paper explains the workings of the Integrated Manure Utilization System (IMUS) in the province of Alberta, Canada.
Address:
http://www.ec.gc.ca/envirozine/english/issues/38/feature2_e.cfm

Source: The World Bank Group (2004)
Title: *Clean power for small towns in FYR Macedonia-Macedonia Mini Hydro-Power Project*
Address:
http://lnweb18.worldbank.org/eca/eca.nsf/0/571ADB32F2F1B23D85256C1D004AAAE5?OpenDocument

Source: European Commission – Energy (2004)
Title: *New and renewable energies*
Address:
http://europa.eu.int/comm/energy/res/index_en.htm

Source: Bureau of Energy Efficiency
Title: *12. Application of non-conventional & renewable energy sources*
Address:
http://www.energymanagertraining.com/Book_all/book4_PDF/4.12App%20of%20Non%20conventional.pdf

Source: U.S. Department of Energy (2004)
Title: *Make your own clean electricity - Case study: Economics of a home wind energy system*
Address:
http://www.eere.energy.gov/consumerinfo/makeelectricity/eval_wintrb_economics_cs.html

Source: World Energy Council (2003)
Title: *The challenge of rural energy poverty in developing countries. Promising technology developments*
Address:
http://www.worldenergy.org/wec-geis/publications/reports/rural/promising_technology_developments/4_4.asp

Source: Schatz Energy Research Center (SERC)
Title: *Fuel cells. How the PEM fuel cell works*
Comment: Very simple chemical information for the PEM fuel cell.
Address:
http://www.humboldt.edu/~serc/fc.html

Title: *Project 4: Aragon 2010 including Hamlet (K)* (2002)
Address:
http://www.solar-gmbh.de/eu3/aragon/index.html

Author: Craig. Peacock (2004)
Title: *South Australian electricity and renewable energy*
Address:
http://users.chariot.net.au/~cpeacock/#Economics

Source: Wind Flow Technology Ltd.
Title: *Wind energy: The perfect solution for New Zealand*
Address:
http://www.windflow.co.nz/backgroundinfo/

Author: Tjarinto S. Tjaroko – Asean Center for Energy (2003)
Title: *Applicability of (new) technological approaches / case studies on mini hydro*
Address:
http://www.asemgreenippnetwork.net/documents/tobedownloaded/knowledgemaps/KM_applicability_new_technological_approach.pdf

Source: Museum Victoria's – Education Gateway (1999)
Title: *Case studies – Pig power*
Comment: Explanation how systems work in a pig farm with 15,000 pigs. This article mentions that this farm's pigs produce the same amount of waste as a city of 40,000. The waste management system created here recycles all the waste and converts it into useable products via an anaerobic digester. It is interesting that water is recovered in different parts of these projects, and used to irrigate the fields close to the pig farms, as well as being used to flush out the pigpens.

Address:
http://www.museum.vic.gov.au/FutureHarvest/case1.html

Title: *Renewable energy: China* (2001)
Comment: The use of PV systems in China, with a market increase of about 20 percent per year.
Address:
http://tcdc.undp.org/experiences/vol8/China.pdf

Source: Sustainable Sources (2001)
Title: *Just how much more efficient are GeoExchange heat pumps?*
Comment: This paper makes a comparison between heat pumps and other equipment, such as air conditioning units, gas furnaces, heating oil furnaces and propane furnaces.
Address:
http://www.greenbuilder.com/sourcebook/groundsource/groundsourceeffic.html#AC

Source: The Geothermal Heat Pump Consortium (1997)
Title: *Waterfront office building – Louisville, Kentucky*
Address:
http://geoexchange.org/pdf/cs-010.pdf

Source: azcentral.com (1998)
Title: *Geothermal heating*
Address:
http://www.azcentral.com/home/diy/geothermal.html

Source: Overview of European Geothermal Industry and Technology Prepared by KAPA Systems, Athens, Greece & EGEC (1997)
Title**:** *Economy of geothermoelectric generation*
Address:
http://www.geotermie.de/egec-geothernet/economics_of_geothermal_electric.htm#_Toc423920728

Source: Sinclair Knight Merz Pty, Ltd.
Title: *Geothermal operations and maintenance*
Address:
http://www.skm.co.nz/index.cfm?id=000531DC-2A68-1B1B-9A9D80E5C4250525

Source: (PEDA) cited in Bureau of Energy Efficiency
Title: *Application of non-conventional & renewable energy sources*

Address:
http://www.energymanagertraining.com/Book_all/book4_PDF/4.12App%20of%20Non%20conventional.pdf

Source: Breakthrough Technologies Institute (2000)
Title: *The online fuel cell information centre*
Address:
http://www.fuelcells.org/fcapps.htm

Authors: F.H. Holcomb, M.J. Binder, N.M. Josefik – US Army (2002)
Title: *Fuel cell technology demonstrations at DoD installations*
Address:
http://www.asc2002.com/summaries/f/FP-10.pdf

Source: Sustainable Development International (2002)
Title: *Wind farm on King Mountain*
Comment: The second largest wind farm in the world will have a capacity to power 140,000 houses.
Address:
http://www.sustdev.org/energy/Industry%20News/05.01/24.01.shtml

Source: Welcome to the website of the IEA Photovoltaic Power Systems Programme (2003)
Title: *1 MW decentralized and building integrated PV system in a new housing area of Amersfoort - Case studies: Netherlands*
Address:
http://www.oja-services.nl/iea-pvps/cases/nld_01.htm

Source: TEKES – Tampere – Finland (2004)
Title: *Solar modules integrated into roof of hypermarket*
Comment: Technical data about this project as well as pictures.
Address:
http://www.tekes.fi/opet/lielahti.htm#Contact

Title: *Solar Thermal Electricity* (1998)
Address:
http://www.teachers.ash.org.au/monkweb/7chap4/7powerplants/solarenergy.htm

Author: Christopher Gronbeck (1994)
Title: *Solar thermal case studies*
Address:
http://sol.crest.org/renewables/re-kiosk/solar/solar-thermal/case-studies/trough-power.shtml

Source: Goethe – Institute (2003)
Title: *World's largest solar power plant*
Comment: Technical details about the PV plant in Hemau, Germany. This source believes that it will take some time before PV energy becomes competitive in a country with as little sun as Germany. However, it also suggests that this type of electricity will become competitive in the Mediterranean by the end of the next decade.
Address:
http://www.goethe.de/kug/ges/uMW/thm/en50516.htm

Author: Eileen J. De Guire - Cambridge Scientific Abstracts (2003)
Title: *Solid oxide fuel cells*
Comment: Good information on fuel cells, especially for SOFC.
Address:
http://www.csa.com/hottopics/Fuecel/overview.html
Ceramic Industry, cited in the above paper
Address:
http://www.ceramicindustry.com/ci/cda/articleinformation/features

Author: Tony Smith - The Register (2003)
Title: *Hitachi readies fuel cell for PDAs* (see Glossary)
Comment: This paper deals with what appears to beone of the first methanol cells for small gadgets on the market. A related link within this paper also announces that Toshiba has engineering portable fuel cells for mobile phones that recharge the phone battery without replacing it. There is more related information at this site.
Address:
http://www.theregister.co.uk/content/68/34485.html

Author: Ian A. Thain
Title: *A brief history of the Wairakei Geothermal Power Project*
Address:
http://www.geotermie.de/egecgeothernet/ci_prof/australia_ozean/new_zealand/a_brief_history_of_the_wairakei_.htm
Title: *Wave power connection heralds new era*
Address:
http://wire0.ises.org/wire/Publications/PressKit.nsf/H/O?Open&B1EECB3B1E755B0AC125699E003D882E

Author: Peter Osborne (2002)
Title: *Electricity from the sea*
Comment: Good information about different devices to use wave energy from the sea.

Address:
http://www.fujitaresearch.com/reports/tidalpower.html

Source: Science News
Title: *Oceans of electricity*
Address:
http://www.phschool.com/science/science_news/articles/oceans_of_electricity.html

Source: ALEP
Title: *Advanced Local Energy Planning*
Comment: Very valuable information from the International Energy Agency. This paper is packed with information about issues such as the Kyoto Protocol, Energy environmental planning, Technical analysis, and Modeling the energy system, and is mainly geared to energy conservation and the use of non-conventional energy sources. Provides examples of the Linear Programming Optimization Model MARKAL with concrete case studies tom exchange experience and it also provides "Guidebook on Advanced Local Energy Planning" (ALEP).
Visiting of this Website is highly recommended.
Address:
http://www.iea-alep.pz.cnr.it/5_background.htm

Author: David Hall (2000)
Title: *Renewable options 3: Biomass -Bringing biomass up-to-date. Poultry power*
Address:
http://www.peopleandplanet.net/doc.php?id=450